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Voluntarily Reporting Discoveries with Career Concerns

경력 문제가 있을 때 성과의 자발적 보고

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Abstract

Voluntarily Reporting Discoveries with Career Concerns

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An agent decides whether to publicly report her discovery. If the productivity of the agent stochastically decreases over time, she may want to delay reporting her discovery to restore the market's belief in a later period. I show that this is possible if discovery occurs rarely and productivity of the agent decays fast enough. I also solve for a dynamic contract that offers the productive agent the most lucrative deal. In such a contract, the agent receives a wage independent of her performance once the agent reveals a single discovery, resembling a tenure contract.

Keywords : Career concerns, repeated game, dynamic contract, adverse selection, information disclosure

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Chapter 1

Introduction

Because the research investments made by individual firms create positive externality, government often provides R&D subsidy to enterprises with large potential. In United States, through fiscal year 2009, more than 26.9 billion dollars have been awarded to SMEs with Small Business Innovation Research (SBIR) program. Naturally, the effectiveness of such subsidization has been studied by several economists (Edison Jr. (2010), Howell (2017)). Specifically, Lee and Jo (2018) reported that in Korea, firms with more patents registered exhibit slower growth, and claimed that the Korean government should not stick to the guideline that prioritizes the number of patents that firms have registered.

There can be several reasons that the number of patents is not correlated, or is even negatively correlated, with the firm's growth rate. For example, it can be caused by the waste of labor on administrative work. In this paper, I focus on the different reason: patent contains the information about the firm's past productivity, not the current productivity. If government lacks the ability to judge the marketability of a patent, a firm has the incentive to use its past - and therefore established - technology to mislead its current capability.

In this paper, I theoretically explore when it is possible to have an equilibrium that firms do not delay patenting its technology. Suppose a firm has a numerous options to get the funding from either public or private sector. If a firm patents a technology, it signals the firm's capability immediately and the firm could secure a sizable amount of fund for a short period. If the firm's productivity is invariant over time, a market would assess the firm's productivity with equally weighted average of its performance over time. However, if the firm's productivity decays over time, the market will take recent performances of the firm into more serious consideration. The firm then has an incentive to hide its discovery only to reveal it in a later period.

My paper belongs to the literature that deals with career concerns, starting with Holmström's (1999). However, I deal with the timing of disclosure, while most of the papers with career concerns study the moral hazard problem. Mukherjee (2008) and Atrobl and Van Wesep (2013) considers the information disclosure problem with career concerns, but the report is made by the firm, not the worker.

My model resembles Bonatti and Hörner (2017) in a sense that both consider a career concerns problem with bandit. Bonatti and Hörner (2017) showed that long-term contract can ameliorate the problem caused by non-contractibility of output. Long-term contract can affect researcher's timing of effort by adjusting the timing of payment. Although my paper considers a long-term contract in a career concern model, its role is quite different. In our model, what is important is agent's incentive to report what she discovers, rather than the timing of effort as in Bonatti and Hörner (2017).

Another feature of my paper is that the agent's type changes over time. Tadelis (1999), Mailath and Samuelson (2001), and Wiseman (2008), among others, studied reputation model where the agent's type changes. Holmström

(1999) also allowed for the agent's type to change in the model of career concerns. However, in Holmström (1999), the transition of type is not directional. In my paper, the agent in the past is more productive than the agent in the future in expectation. Therefore, more recent information is more valuable, which makes the timing of discovery relevant.

Chapter 2

Model

2.1 Basic Model

Player 1 (researcher) and player 2 (firm) live for T periods. At each period t, researcher's type is binary: $\theta_t = 0, 1$. I describe $\theta_t = 1$ as the productive researcher, and $\theta_t = 0$ as the unproductive researcher at period t. If $\theta_{t-1} = 1$, $\theta_t = 1$ with probability q, and $\theta_t = 0$ with probability $1-q$, where $q \in (0,1)$. If $\theta_{t-1} = 0$, $\theta_t = 0$: once the researcher becomes unproductive, she will be so forever. This assumption is to capture that the researcher's productivity decreases over time. Discovery is binary, and made by player 1 only if she is productive. Let μ_t be the indicator for whether she made a discovery at period t. With probability $\lambda\theta_t$, $\mu_t = 1$ and with probability $1-\lambda\theta_t$, $\mu_t = 0$ where $\lambda \in (0,1)$.

At period 1, player 1 chooses $a_1 \in \{0, \mu_t\}$. Define $\eta_1 = \mu_1 - a_1$. At period t, player 1 chooses $a_t \in \{0, \cdots, \mu_t + \eta_{t-1}\}$. Define $\eta_t = \mu_t + \eta_{t-1} - a_t$. We interpret a_t as the number of discoveries player 1 reports. η_t is the cumulatively counted discoveries after period t. At period t, both players can observe $(a_s)_{s=1}^{t-1}$. Player 2 cannot observe θ_t and μ_t, while player 1 can. Players share the common belief that $\theta_0 = 1$ with probability p_0.

At each period, the wage player 2 pays to player 1, w_t, is determined competitively. Player 2's ex-post payoff is $a_t - w_t$: the firm owns the patent right and the value of patent is normalized to 1. The wage cannot depend on a_t as it is non-contractible. Player 1 and player 2 do not discount future payoff. Player 1's payoff is simply the sum of her wage, $\sum_{t=1}^{T} w_t$. Note that Her payoff is not directly affected by her action a_t. Player 2's payoff is $\sum_{t=1}^{T}(a-t-w_t)$.

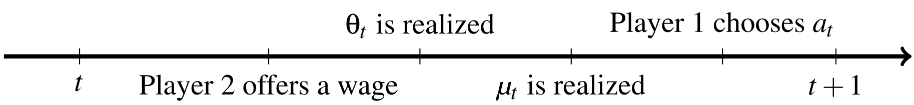

Figure 1: Timing of Moves in a Period

The solution concept I use for this paper belongs to perfect Bayesian equilibrium. I will specifically look for a "truth-telling" equilibrium, where player 1 reports her single discovery whenever possible: $a_t = 1$ if $\mu_t = 1$ or $\eta_{t-1} > 0$ at any period t on every possible history.

2.2 Belief

In determining a wage at period t, η_{t-1} and θ_t are the unknowns that player 2 explicitly concerns. Since our focus is on the truth-telling equilibrium, player 2's belief on η_{t-1} at period t is trivial: he believes discovery is reported whenever possible, therefore $\eta_{t-1} = 0$ with probability 1. Player 2 shall also have a belief that $\eta_{t-1} = 0$ on the off-the-equilibrium path. Let p_t be the player 2's belief on $\theta_t = 1$ at period t. Define $\bar{t}$ as the most recent period s such that $a_s \geq 1$. Set $\bar{t} = 0$ if $a_1 = \cdots = a_{t-1} = 0$. Then, conditioning on being in the truth-telling equilibrium, $\bar{t}$ is sufficient statistic of history $(a_s)_{s=1}^{t-1}$ for calculating p_t. If $\bar{t} > 0$, player 2 updates his belief according to the Bayes' rule:

$$p_t\left((a_s)_{s=1}^{t-1}\right) = p_t(\bar{t}) = \frac{q^{t-\bar{t}}(1-\lambda)^{t-\bar{t}-1}}{1-\lambda q\sum_{s=1}^{t-\bar{t}-1}\left((1-\lambda)q\right)^{s-1}}, \tag{2.1}$$

and if $\bar{t}=0$,

$$p_t(\bar{t}) = \frac{q^{t-\bar{t}}(1-\lambda)^{t-\bar{t}-1}p_0}{1-\lambda q p_0\sum_{s=1}^{t-\bar{t}-1}\left((1-\lambda)q\right)^{s-1}}. \tag{2.2}$$

In truth-telling equilibrium, the wage at period t is determined as $w_t = \lambda p_t$, which is the player 2's belief that player 1 will come up with a discovery.

We will say that the game has a *truth-telling equilibrium* if player 1 cannot do better off by deviating from a truth-telling strategy, that is, choosing $a_t = 1$ if $\mu_t = 1$ or $\eta_{t-1} > 0$ and choosing $a_t = 0$ otherwise, at any period t and any history $(a_s)_{t=1}^{t-1}$, where player 2 updates his belief as (2.1) and (2.2) and the wage at each period is determined as $w_t = \lambda p_t$.

Chapter 3

Equilibrium

I will first solve for the case where the game is repeated three times.

Proposition 1. *If $T = 3$, the game has a truth-telling equilibrium.*

Proof. Player 1 is indifferent between what she chooses with a_3. Also, p_3 is maximized if $a_2 = 1$, therefore it is also in player 1's interest to choose $a_2 = 1$ if $\mu_2 = 1$ or $\eta_1 = 1$. Now suppose $\mu_1 = 1$. If player 1 chooses $a_1 = 1$, from $t = 2$, she gets the expected payoff of

$$\lambda q + \lambda q^2.$$

Note that due to Martingale property, her expected wage at $t = 3$ is the expected probability, unconditionally on μ_2, of making a discovery at $t = 3$. Consider a deviation to $a_1 = 0$. This is the only deviation (to pure strategy) that we have not checked. At $t = 2$, player 1 will receive

$$w_2 = \lambda q_2 = \frac{\lambda(1-\lambda)q^2}{1-\lambda q},$$

and by choosing $a_2 = 1$, she can ensure

$$w_3 = \lambda q.$$

We can see that

$$\lambda q + \lambda q^2 > \frac{\lambda(1-\lambda)q^2 p_0}{1-\lambda q} + \lambda q$$

for any λ, q and p_0, so that this deviation is never profitable. $\square$

The deviation gives less payoff for $t = 2$ and more payoff for $t = 3$. Therefore, this result holds even if player 1 discounts the future payoff.

If player 1 faces remaining period as short as three periods, discovery can be reported pertinently. In this scenario, player 1 is also paid with maximum expected wage she can get. Hiding discovery can be profitable, if player 1 can delay her report to pop up player 2's belief in a later period. This is the case with $T = 4$, in which after the first period the game is played several times so that popping up player 2's belief eventually pays back.

Proposition 2. *If $T = 4$, the game does not have a truth-telling equilibrium if $\frac{(1-\lambda)p_0}{1-\lambda q} > q$.*

Proof. Consider $t = 1$ and suppose $\mu_1 = 1$. Choosing $a_1 = 1$ gives player 1 the expected payoff of

$$\lambda q + \lambda q^2 + \lambda q^3.$$

If she deviates to $a_1 = 0$, she will get $w_2 = \frac{\lambda(1-\lambda)q^2 p_0}{1-\lambda q}$ at period 2. Also, she shall choose $a_2 = 1$ to get $w_3 = \lambda q$ at period 3. She will also choose $a_3 = 1$ if $\mu_3 = 1$ or $\eta_2 = \mu_2 = 1$. The probability of the event $\mu_2 = \mu_3 = 0$ conditioning on $\mu_1 = 1$ is

$$(1-\lambda)q(1-\lambda q) + (1-q).$$

Therefore, the expected wage she will receive at $t = 4$ is

$$\{(1-\lambda)q(1-\lambda q)+(1-q)\}\lambda q+\{q-(1-\lambda)q(1-\lambda q)\}\frac{\lambda(1-\lambda)q^2}{1-\lambda q}$$
$$=\lambda q\{(1-\lambda)q(1-\lambda q)+(1-q)+(1-(1-\lambda)q)\frac{\lambda(1-\lambda)q^2}{1-\lambda q}\}. \quad (3.1)$$

Specifically, this is higher than λq^2, which is the expected wage she will receive if she chooses $a_3 = 1$ only if $\mu_2 = 1$ and $a_3 = 0$ otherwise. Therefore, the sufficient condition that the deviation is profitable is

$$\lambda q+\lambda q^2+\lambda q^3<\frac{\lambda(1-\lambda)q^2 p_0}{1-\lambda q}+\lambda q+\lambda q^2,$$

which reduces to $\frac{(1-\lambda)p_0}{1-\lambda q} > q$. □

In the proof, I only rule out the specific kind of deviation in the first period. At $t = 3,4$, by the same proof of Proposition 1, player 1 has no incentive to deviate from truth-telling. If only one of $\mu_2 = 1$ or $\eta_1 = 1$ holds, the deviation incentive at $t = 2$ is the same with Proposition 1. If $\mu_2 = \eta_1 = 1$, setting $a_2 = a_3 = 1$ gives player 1 the maximum payoff. Since there is no other profitable deviation, we can obtain a necessary and sufficient condition for the game to have a truth-telling equilibrium by directly using (3.1).

The sufficient condition in Proposition 2 is not satisfied if $p_0 \le q$. If $p_0 > q$, the condition is equivalent to

$$\lambda<\frac{p_0-q}{p_0-q^2}. \quad (3.2)$$

The right-hand side of 3.2 is decreasing in q. We can observe that a truth-telling equilibrium can possibly exist only if discovery is not rare and productivity decays slowly.

If the researcher's productivity is relatively invariant over time, the timing of report is not necessarily essential in evaluating the firm's type. In truth-telling equilibrium, the firm will assess researcher's productivity by looking at all the past reports with equal relevance. Therefore, the researcher will likely to report to as soon as possible, to get more wage in earlier period without sacrificing a future payoff.

If the discovery is not rare, the wage will fall more sharply when the researcher fails to report. Therefore, she will have more incentive to pop up the firm's belief in a later period.

Chapter 4

Dynamic contract

In the previous section, we learned that spot contract alone cannot always induce the disclosure of discovery. I now consider a dynamic contract, where player 2 offers a wage plan $w_t\left((a_s)_{s=1}^{t-1}\right)$ that depends on the history of player 1's action. Player 2 can only offer a contract that satisfies *limited liability* constraint, that is, $w_t((a_s)_{s=1}^{t-1}) \geq 0$ for all t and $(a_s)_{s=1}^{t-1}$.

It is assumed that player 1 can break a contract after any period, while player 2 cannot. I shall continue to focus on the case $T = 4$. Since output at period t is not contractible for w_t, the continuation payoff that the menu provides should be at least what player 1 can get in the market. We will call that a contract is *individually rational* if at any period t with any history $(a_s)_{s=1}^{t-1}$,

$$\sum_{t'=t}^{4}(E[w_{t'}|(a_s)_{s=1}^{t-1}] - \lambda p_t\left((a'_s)_{s'=t}^{t'-1}\right) q^{t'-t}) \geq 0, \tag{4.1}$$

where

$$E[w_{t'}|(a_s)_{s=1}^{t-1}] = \sum_{(a'_s)_{s'=t}^{t'-1}} w_{t'}\left((a_s)_{s=1}^{t-1}, (a_{s'})_{s'=t}^{t'-1}\right) Pr((a_{s'})_{s'=t}^{t'-1}|(a_s)_{s=1}^{t-1}).$$

Note that $\lambda \sum_{t'=t}^{T} p_t\left((a_s)_{s=1}^{t-1}\right) q^{t'-t}$ is the expected payoff that player 1 can obtain in the market.

Moreover, we will say an individually rational contract is *implementable* if (4.1) binds for a null history $\emptyset$ and any history $((a_s)_{s=1}^{t-2},1)$. Recall that a_t is not contractible. If a contract is implementable, the wage plan can be mimicked by the following series of simple temporary wage plan:

- At $t=1$, player 2 offers a temporary wage plan $w_1(\emptyset)$, $w_2(0)$, $w_3(0,0)$, $w_4(0,0,0)$.
- At $t=2$, if $a_1=0$, wage is given by the contract.
- At $t=2$, if $a_1=1$, player 2 newly offers a temporary wage plan $w_2(1)$, $w_3(1,0)$, $w_4(1,0,0)$.
- Likewise, a new commitment is offered at any history $((a_s)_{s=1}^{t-2},1)$.

Basically, player 1 stays within the contract and receives the promised wage only if she does not report a discovery. If she does report a discovery, she renegotiates with the current employer, because she can escape the contract and find a new employer in the market.

Finally, in a four period game, a contract is called *incentive compatible* if the followings are satisfied:

$$
\begin{aligned}
& w_2(1)+E[w_3|(1)]+E[w_4|(1)] \geq w_2(0)+w_3(0,1) \\
& \quad +\{(1-\lambda)q(1-\lambda q)+q\}w_4(0,1,1)+\{(1-\lambda)q(1-\lambda q)+(1-q)\}w_4(0,1,0), \\
& w_3(a_1,1)+E[w_4|(a_1,1)] \geq w_3(a_1,0)+w_4(a_1,0,1), \\
& w_4(a_1,a_2,1) \geq w_4(a_1,a_2,0).
\end{aligned}
$$

Three inequalities above are the condition under which none of the one-step deviations are profitable.

There are several contracts that is individually rational and incentive compatible. For example, consider the following contract: $w_1 = w_2 = w_3 = 0$, and $w_4 = \sum_{t=1}^{4} \lambda p_0 q^{t-1}$. Because lump-sum payment is given at the end of the period, player 1 will not pull out of the contract to the end, and she has no reason to deviate from truth-telling. However, because of adverse selection at period 1, a contract cannot separate between $\theta_0 = 1$ and $\theta_0 = 0$. If player 2 knows that player 1 will accept the contract only if $\theta_0 = 0$, he will offer her nothing. Then a contract targeting for $\theta_0 = 1$ should satisfy $w_t\left((0,0,\cdots,0)\right) = 0$ for all t, but this violates individual rationality at $t = T$. Therefore, a market will provide a contract that maximizes the expected payoff for player 1 whose initial type is $\theta_0 = 1$. The problem is equivalent to minimizing the expected payoff for player 1 whose initial type is $\theta_0 = 0$, which is

$$w_1(\emptyset) + w_2(0) + w_3(0,0) + w_4(0,0,0). \tag{4.2}$$

To minimize (4.2), a contract should offer lower wage for a history with negative report, and therefore individual rationality will bind for a "bad" history. Without incentive compatibility condition, separation is most extreme with spot contract. However, spot contract does not always satisfy incentive compatibility as we have seen in Proposition 1. With incentive compatibility condition, we have the following result:

Proposition 3. *Suppose* $\frac{(1-\lambda)p_0}{1-\lambda q} > q$. *If a contract is individually rational, incentive compatible, implementable and satisfies limited liability,* $w_1(\emptyset) +$

$w_2(0) + w_3(0,0) + w_4(0,0,0)$ *is minimized by choosing*

$$\begin{aligned}
w_2(0) &= \lambda q^3, \\
w_3(0,0) &= \frac{\lambda(1-\lambda)q^2 p_0}{1-\lambda q} + \lambda q - \lambda q^3 \\
w_3(0,1) &\leq \lambda q^2 \\
w_4(0,1,0) = w_4(0,1,1) &= \lambda q + \lambda q^2 - w_3(0,1)
\end{aligned}$$

and the wage for the rest history is same as the spot contract.

Proof. From individual rationality and implementability at histories $\emptyset$, (1), $(0,1)$, $(0,0,1)$ and $(0,0,0)$, we have

$$\sum_{t'=1}^{4}(E[w_{t'}|\emptyset] - \lambda p_0 q^{t'}) = 0 \tag{4.3}$$

$$\sum_{t'=2}^{4}(E[w_{t'}|(1)] - p_2(1)q^{t'-2}) = 0 \tag{4.4}$$

$$\sum_{t'=3}^{4}(E[w_{t'}|(0,1)] - p_3(0,1)q^{t'-3}) = 0 \tag{4.5}$$

$$w_4((0,0,1)) - \lambda p_4(0,0,1) = 0 \tag{4.6}$$

$$w_4((0,0,0)) - \lambda p_4(0,0,0) = 0 \tag{4.7}$$

By subtracting (4.4), (4.5) and (4.6) from (4.3), we obtain

$$\begin{aligned}
w_1(\emptyset) + w_2(0)Pr(0) + w_3(0,0)Pr(0,0) + w_4(0,0,0)Pr(0,0,0) \\
= \lambda\left(p_1(\emptyset) + p_2(0) + p_3(0,0) + p_4(0,0,0)\right).
\end{aligned} \tag{4.8}$$

Since the right-hand side of (4.8) is constant, and $1 > Pr(0) > Pr(0,0) > Pr(0,0,0)$, the optimal wage plan should maximize $w_1(\emptyset)$, and then $w_2(0)$, and so on. $w_1(\emptyset)$ is maximized when individual rationality at the history (0) binds, in which case $w_1(\emptyset)$ is same as the spot contract.

Maximum of $w_2(0)$ is given by the incentive compatibility. Incentive compatibility condition is most generous when $w_4(0,1,0) = w_4(0,1,1)$. It follows that $w_2(0) = \lambda q^3$. $\square$

The contract differs from spot contract in two ways. Firstly, $w_2(0)$ is determined so that incentive compatibility condition binds. Secondly, after the history $(0,1)$, the payoff at period 4 is pooled between good outcome and bad outcome. Hiding a discovery creates different beliefs on future type for player 1 and player 2. Player 1 can exploit this if she knows she has a higher chance to get a higher wage. Because uncertainty does not arise once player 1 reports discovery, optimal contract can deter such opportunity and make the incentive compatibility condition less demanding.

Chapter 5

Discussion

5.1 Extensions

In this paper, I concentrated on a truth-telling equilibrium. However, there are actually many perfect Bayesian equilibria in this game. Specifically, there can be an equilibrium, that is not a truth-telling equilibrium, in which all the reports will be eventually reported.

Suppose $T = 4$ and $p_0 = 1$. If $q > \frac{1}{2}$, there exists a following perfect Bayesian equilibrium. At period 1, player 1 does not report, and $w_1 = 0$. At period 2, player 1 reports every discovery she has: $a_2 = \mu_1 + \mu_2$, and she is paid with

$$w_2 = \lambda q + \lambda q^2.$$

At $t = 3, 4$, she chooses $a_t = \mu_t$. Since player 2 believes that player 1 stores her discovery at period 1, reporting a single discovery is not enough to persuade him that $\theta_2 = 1$. This gives player 1 an incentive to report all. One can argue that this equilibrium is just as good as the truth-telling equilibrium. However, if we introduce the discount factor, it is more beneficial when a discovery is reported as soon as possible.

My model has a multiple equilibria because reporting a discovery does not directly affect player 1's payoff. Although I abstracted from this issue by only focusing on a truth-telling equilibrium, one could reasonably introduce a cost or a benefit for reporting a discovery. This way, the set of equilibria may shrink and more robust result could be obtained. I leave this problem for future research.

Also, it can be argued that a truth-telling equilibrium in my game vanishes if T goes to infinity. Because player 1 eventually becomes unproductive with probability 1, it is true that without discounting a truth-telling equilibrium does not exist with infinite horizon. However, if we introduce a discount factor that is small enough, it is possible to obtain a truth-telling equilibrium. The goal of this paper is to identify when it is possible to have a truth-telling equilibrium. Therefore, my result is not undermined by the fact that a truth-telling equilibrium does not exist with a discount factor that is high enough.

5.2 Conclusion

In this paper, I derived a condition under which a truth-telling equilibrium exists in a model of career concerns. First, firm's productivity should decay slowly. This suggests that government should adopt a different R&D policy for a different industry, because a firm's relative productivity against the market, which essentially is the speed of decay, varies across the industry. Second, a discovery should occur rarely. Government should therefore give R%D subsidy to a high-risk and high-return enterprise.

Unlike moral hazard problem that has been vastly dealt in the literature, in my model hiding an information directly increases the agent's future payoff. I showed that the first-best is not achievable under certain conditions. In response, the market may use a dynamic contract that states the contingent wage for each history.

My paper can be used in a situation where the outcome is stochastic and non-contractible. Particularly, academia is one of such market. I showed that with dynamic contract, an agent's payoff will be invariant once she reports one meaningful discovery. This feature resembles the tenure contract. There can be many reasons that universities use tenure contract. Notwithstanding, my paper suggests that one advantage of tenure contract is that junior professors have more incentive to publish an article promptly, with their affiliation listed as the very university that offered a tenure contract.

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국 문 초 록

대리인이 자신의 발견을 공개할지 결정하고자 한다. 만약 대리인의 생산성이 시간에 따라 확률적으로 감소한다면, 발견을 나중에 공개함으로서 자신에 대한 시장의 평가를 추후에 끌어올릴 수 있을 것이다. 이 논문에서는 발견이 드물고 대리인의 생산성이 빠르게 감소하면 균형에서 이러한 상황이 가능하다는 것을 보인다. 또한 저자는 생산성 있는 대리인에게 가장 유리한 동적 계약의 형태를 구한다. 이 경우 대리인은, 마치 종신 계약과 같이, 한번 발견을 공표한 이후에는 미래의 성과와 관계없이 일정한 수익을 약속받는다.

주요어 : 경력 문제, 반복 게임, 동적 계약, 역선택, 정보 공개

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